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DISCOVERY AND DEVELOPMENT OF THE PIMA COPPER DEPOSIT, PIMA MINING CO., PIMA COUNTY, ARIZ.

By R. E. Thurmond and W. R. Storms

United States Department of the Interior — January 1958

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DISCOVERY AND DEVELOPMENT OF THE PIMA COPPER DEPOSIT, PIMA MINING CO., PIMA COUNTY, ARIZ.

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R. E. Thurmond[1/] and W. R. Storms[2/]

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SUMMARY AND INTRODUCTION

This paper, which describes the discovery, exploration, and development of the Pima copper deposit of the Pima Mining Co., Pima County, Ariz., is one of a series being prepared by the Bureau of Mines on mining methods in various United States districts. The Pima deposit is unique because it was discovered by geophysical means beneath 200 feet of overburden.

The Pima mine is in the northeastern part of the Pima mining district in the relatively flat area between the northeastern end of the Sierrita Mountains and the Santa Cruz Valley (figs. 1 and 2). The mine is in the northern part of sec. 1, T. 17 S., R. 12 E., about 20 miles south-southwest of Tucson. The climate is typical of the desert regions of southern Arizona, with hot summers and mild winters. Annual precipitation is about 12 inches. The area is covered with cacti, scattered desert brush, and a few paloverde-trees. The Santa Cruz River, about 6 miles east of the mine, is the nearest surface water.

This report gives a brief history of the district, describes the geology in the immediate area, and presents a detailed description of the discovery of the deposit by geophysical means and the subsequent exploration by surface drill holes. Development of the deposit then is reviewed, with sampling methods and an estimate of ore reserves. The planned method of stoping and methods of underground transportation, ventilation, mine drainage, and safety practice are briefly described. A short section on costs also is included.

Underground development was stopped in the autumn of 1955, when it was decided to mine the ore by an open-pit method; little actual underground stoping was done.

This paper discusses only the discovery of the deposit and the initial underground development. It does not cover the later open-pit development and mining methods.

ACKNOWLEDGMENTS

Acknowledgment is made to the executives of the Pima Mining Co. for permission to publish this paper, especially to Paul W. Allen, general manager, and E. D. Spaulding, resident manager. Acknowledgment also is made to W. E. Heinrichs, Jr., formerly with the United Geophysical Co. but now with the exploration department of the Union Oil Co. Thurmond, Heinrichs, and Spaulding supervised the initial geophysical work and planned the early mine development.

HISTORY[3/]

Some mining was done in the Pima district before 1875. In 1880 the San Xavier Mining & Smelting Co. was organized to work the San Xavier mine. This and several other small mines in the Sierrita Mountains operated until 1893.

3/ Wilson, E. D., Chapter IV - Pima District, Arizona Zinc and Lead Deposits, Part I: Arizona Bureau of Mines Bull. 156, 1950, pp. 43-44.

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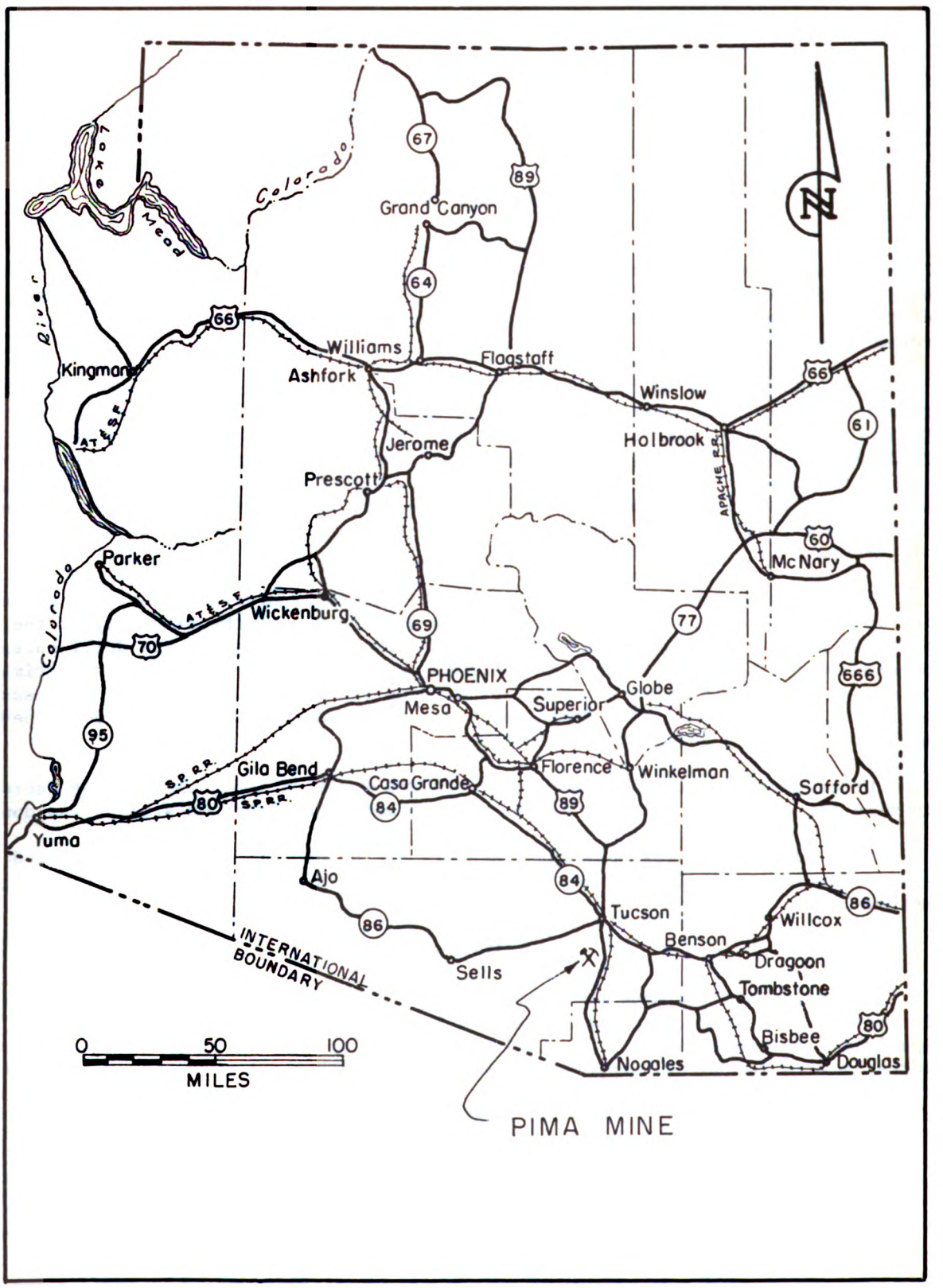

Figure 1. - Location map.

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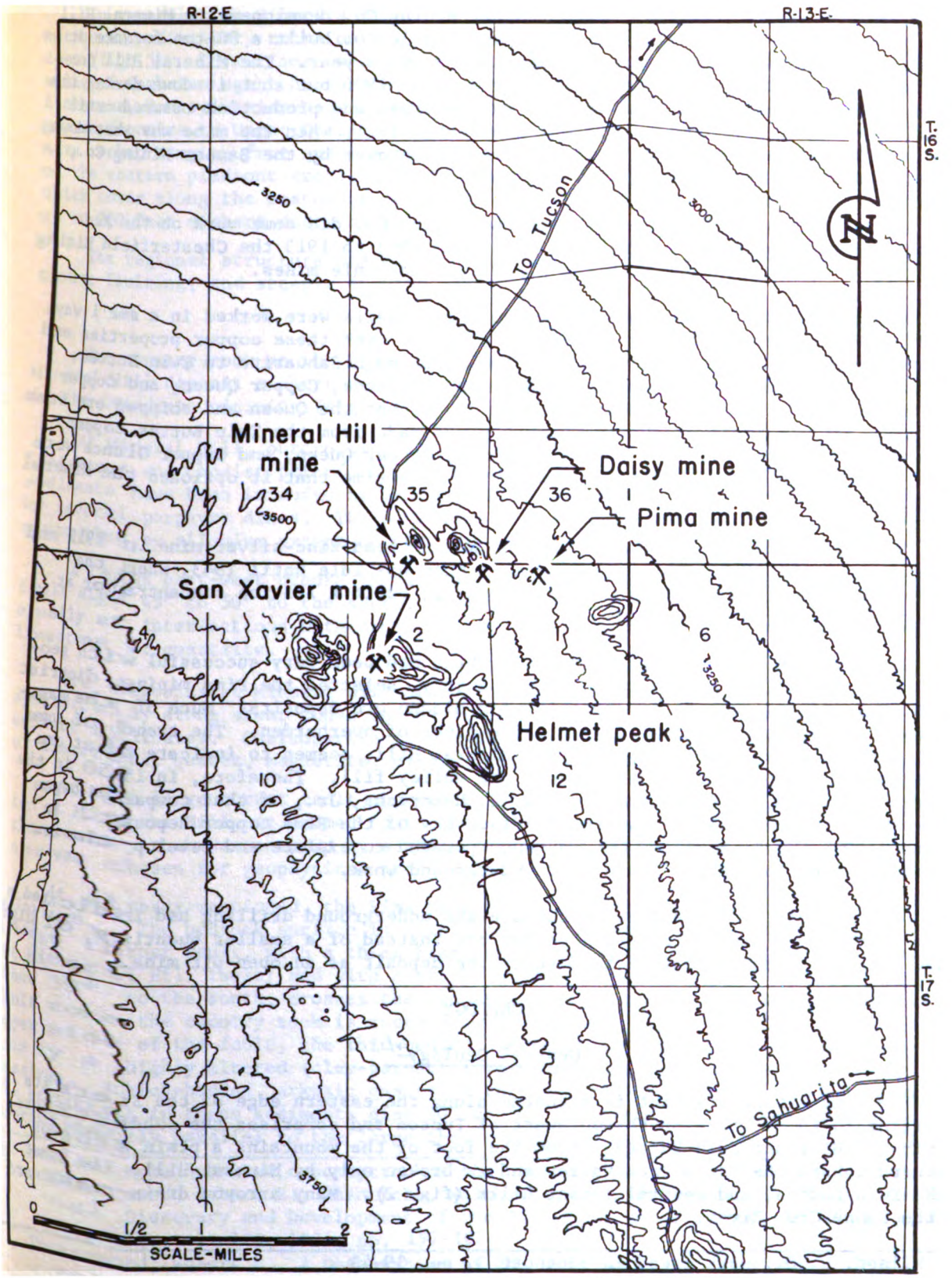

Figure 2. - Surface topography.

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From 1882 until 1884 the Emperor Copper Mining Co. developed the Mineral Hill copper deposits. In 1898 the Azurite Copper & Gold Co. built a 30-ton furnace at the Mineral Hill mine and produced copper for about a year. The Mineral Hill Consolidated Copper Co. took over this property about 1906 but shut it down during the panic of 1907. In 1916 the old smelter was enlarged and production resumed until about 1919. Some development work was done until 1921, when the mine was shut down; it was not reopened until 1951. It then was taken over by the Banner Mining Co., the present owner and operator.

During 1906 and 1907 Calumet & Arizona Mining Co. did some work on the Red Carbonate group southwest of Twin Buttes. From 1908 to 1913 the Chesterfield Mining Co. shipped lead-silver ore from the Esperanza and Annie mines.

During the 1890's, the Twin Buttes copper deposits were worked in a small way. In 1903 the Twin Buttes Mining & Smelting Co. took over these copper properties and by 1906 had constructed a railroad from Tucson through Sahuarita to Twin Buttes. This company operated the Senator Morgan, Copper Glance, Copper Queen, and Copper King mines until 1914. The Midland Copper Co. bought the Queen and shipped ore from it until 1926. A small production probably was made from the Twin Buttes copper mines from 1926 to 1951, when the Copper King, Copper Queen, and Copper Glance were taken over by the Banner Mining Co. about the same time that it optioned the Mineral Hill mine.

The Empire Zinc Co. purchased the San Xavier lead-zinc-silver mine in 1912 and shipped ore until 1918. The mine evidently then was idle until 1943, when the Eagle-Picher Mining & Smelting Co. purchased it, built a 175-ton concentrator at Sahuarita, and began production.

In 1950, the United Geophysical Co., which had been very successful with geophysical-prospecting methods in the oil industry, selected the Pima mining district for a study of its methods in searching for hidden ore deposits. Much of the eastern part of the area was buried by a thick cover of overburden. The trend of some known ore deposits, especially those at Mineral Hill, seemed to indicate that ore bodies might be found to the east under the valley fill. Therefore, in 1950 in the Mineral Hill area, R. E. Thurmond and W. E. Heinrichs, Jr., of that company began the work, which eventually resulted in discovery of the Pima copper deposit. In November 1951 the Pima Mining Co. was incorporated to explore and develop the new ore body further by shaft sinking and underground work.

Late in 1955, after extensive surface and underground drilling had indicated a large quantity of fairly low-grade copper ore instead of a smaller quantity of high-grade ore, the company decided to develop the deposit as an open-pit mine.

GEOLOGY

General Geology[4/]

The Pima mining district is situated along the eastern edge of the Sierrita Mountains 20 to 30 miles south-southwest of Tucson and comprises the subdistricts of Mineral Hill and Twin Buttes. From the foot of the mountains a plain slopes eastward toward the Santa Cruz Valley and is broken only by Mineral Hill, Helmet Peak, Twin Buttes, and several lesser hills (fig. 2). Many arroyos drain eastward to the Santa Cruz River.

4/ Wilson, E. D., work cited in footnote 3, pp. 39-43.

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In general, the Sierrita Mountains are composed of a granitic core with metamorphosed sedimentary rocks on the west slope and much less altered sediments on the east (fig. 3). Formations on the east range from Bolsa quartzite and Abrigo limestone of Cambrian age, through Devonian Martin limestone, Mississippian Escabrosa limestone, Pennsylvanian Naco limestone, Permian shales, limestones, quartzites, and gypsum deposits to Upper Cretaceous volcanics and sediments. Coarse-grained intrusive rocks, ranging from granite and quartz monzonite to granodiorite, underlie much of the eastern piedmont area. Alluvial fans resulting from recent erosion form a thick cover along the eastern edge of the district; this cover ranges in thickness up to 200 feet a short distance east of Mineral Hill.

The regional structure has been complicated by folding, overturning, low-angle thrust faulting, and steeply dipping faulting.

Ore Deposits

The country rock at the Pima mine is covered by 200 feet of alluvium. The Mineral Hill deposit a short distance westward is the only exposed mineral deposit in the immediate vicinity (fig. 4).

At Mineral Hill, outcropping sedimentary rocks range in age from Cambrian to Cretaceous and consist principally of limestones, shales, and quartzites. These sediments have been intruded by granite (which underlies much of the area) and cut by several porphyry dikes. The sediments form a small group of hills, entirely surrounded by alluvium except on the west side, where granite outcrops.

A large east-west preore thrust fault traverses the Mineral Hill area; this fault dips 45° to 50° to the south. Mineralization occurs along this large fault, usually at intersections with cross faults, or at or near intrusive contacts with limestone or quartzite.

Ore deposits at Mineral Hill are of contact metamorphic type and usually occur sporadically along shear zones in the limestone and also disseminated through the contact silicates. Chalcopyrite is the principal ore mineral. The gangue consists of limestone, quartz, magnetite, pyrite, hematite, calcite, and contact silicates.

As the large thrust fault apparently was the primary control for the ore bodies at Mineral Hill, it seemed that other deposits might be found to the east where the country rock was covered by a thick overburden of alluvium. Therefore, that area was chosen for geophysical prospecting.

As already mentioned, the Pima mine area is covered with up to 200 feet of alluvium. The bedrock surface is fairly regular and dips gently northeastward. A large thrust fault, with a thick brecciated zone (evidently a continuation of the Mineral Hill fault) and with a strike of approximately N. 80° E. and a dip of about 50° to the south, crosses the property from west to east. Beneath this large fault zone the country rock is rusty brown quartzite. Lying immediately upon the upper side of the fault, the thin-bedded, serpentinized dolomitic limestone is overlain by a highly altered (clay-garnet) limestone, which in turn is overlain by a massive, thick-bedded, arkosic quartzite varying from rusty brown to light gray. The bedding in these sediments dips 30° to 50° southward and strikes about N. 80° E., approximately parallel to the large thrust fault.5/ The sediments seem to be Permian.

5/ For a more detailed description of the geology, see the following publications:
Thurmond, Robert E., Heinrichs, Walter E., Jr., and Spaulding, E. D., Geophysical Discovery and Development of the Pima Mine, Pima County, Arizona: AIME Trans., vol. 199, 1954, pp. 197-202.
Thurmond, Robert E., A Description of the Pima Ore Body: Min. Cong. Jour., vol. 41, No. 1, January 1955, pp. 27-30, 64.

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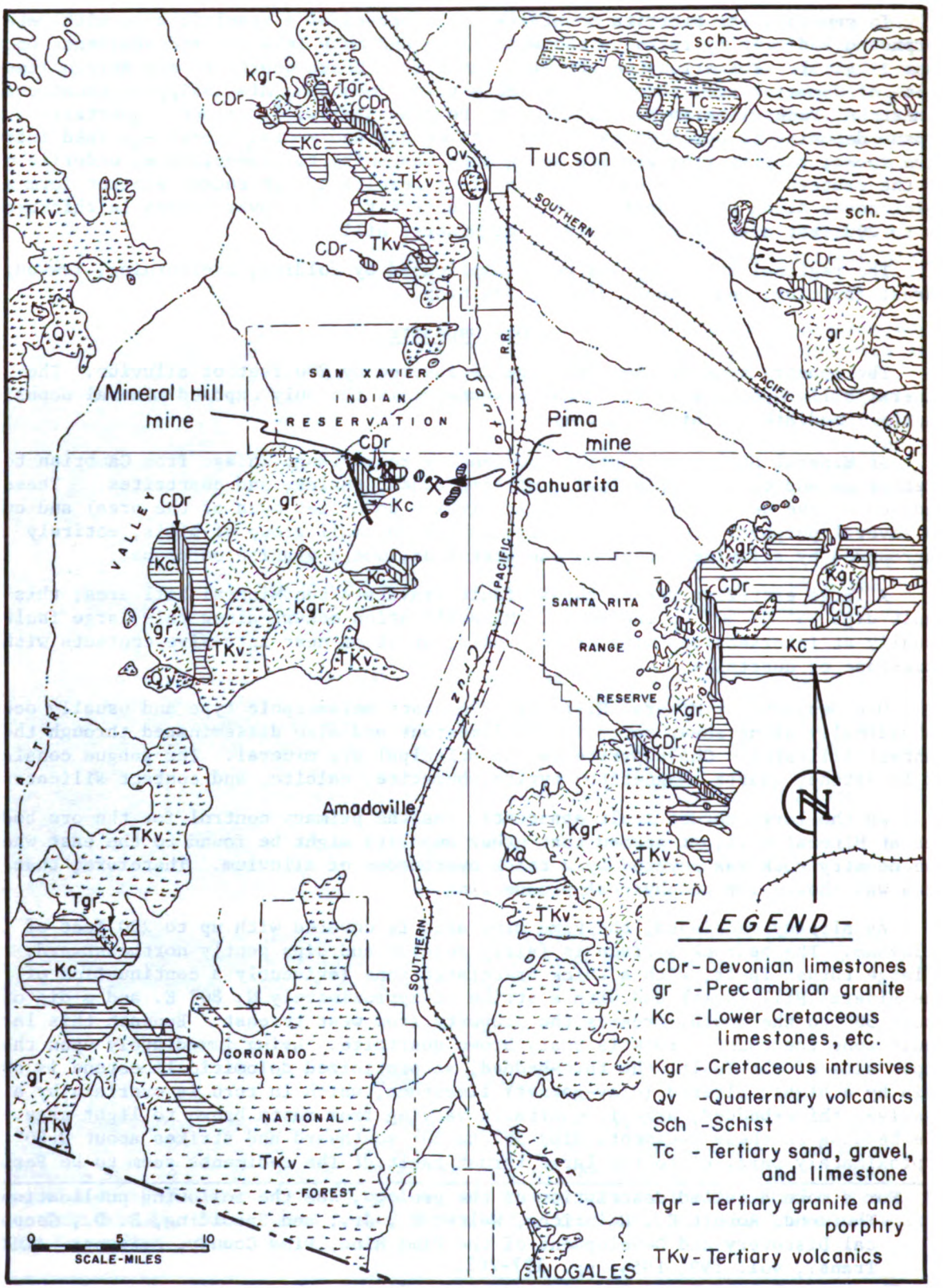

Figure 3. - Regional geology.

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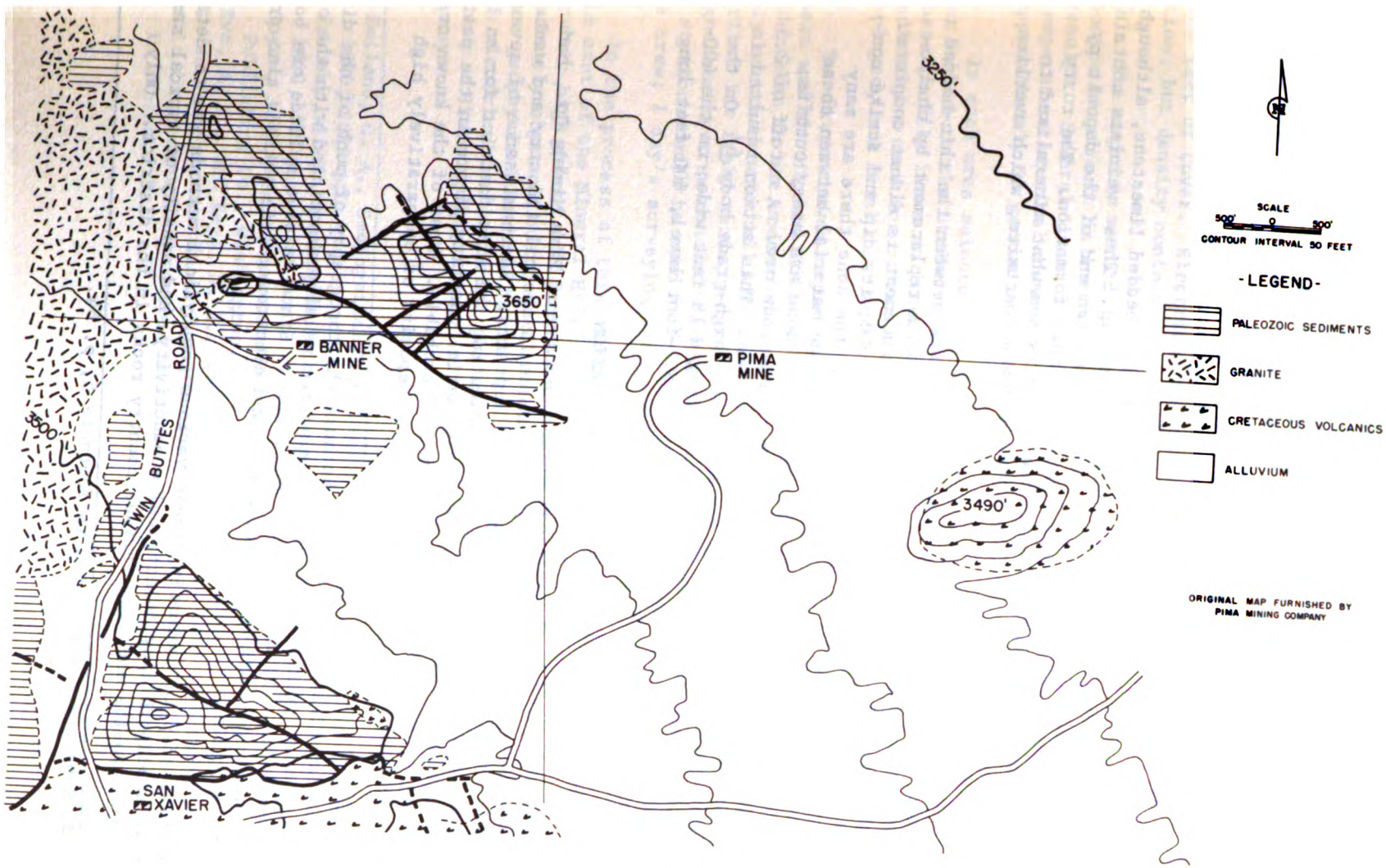

Figure 4. - Mineral Hill area.

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The Pima massive chalcopyrite ore bodies occur between the serpentinized dolomitic limestone and the highly altered clay-garnet limestone in an intensely altered zone consisting of a mixture of kaolin and small garnets, with some limestone remnants. This alteration suggests the possibility of a nearby intrusive. The thin-bedded dolomitic limestone usually forms the foot wall of the massive ore bodies, although in a few places a thin bed of this formation forms the hanging wall. Where the ore body is absent, this thin-bedded, serpentinized, dolomitic limestone grades into the highly altered, clay-garnet limestone, with one formation fingering into the other.

No massive mineralization has been found in the thin-bedded limestone, although it is cut by many small veinlets, usually along the bedding. These veinlets contain chalcopyrite, pyrite, magnetite, and quartz. On the eastern end of the deposit pyrite and chalcopyrite are widely disseminated through this formation. The rusty brown quartzite, which underlies the fault zone, also is somewhat mineralized to the east with pyrite and chalcopyrite, as is the arkosic quartzite, which overlies the altered limestone.

The high-grade copper sulfide ore body, which occurs between the thin-bedded serpentinized limestone and the clay-garnet material, is a replacement by chalcopyrite in the clay-garnet limestone; in places the replacement is almost complete. It extends from above the 300-foot level to below the 500; its dip and strike conform to the general position of the formation. Within the zone there are many shoots and pods of massive chalcopyrite with lower grade material between these pods. Both the foot wall and hanging wall of this ore zone are assay cutoffs; copper content gradually decreases away from the high-grade ore. A cutoff of 2.5 percent copper was used to outline this high-grade zone. This action resulted in an average value of 4.5 percent copper for the entire high-grade body.6/ On the 300-foot level this zone was 570 feet long and averaged 18 feet wide; on the 400-foot level, 790 feet long and 42 feet wide; and on the 500-foot level, 600 feet long and 54 feet wide.

PROSPECTING AND EXPLORATION

United Geophysical Co., the original parent company of Pima Mining Co., had successfully applied geophysical-prospecting methods in the oil industry and wanted to test its methods in searching for hidden ore deposits. Reconnaissance of several mining districts in the Southwest resulted in selecting the Pima district for an initial trial. This district had produced a substantial quantity of ore in the past, and the discovery of additional ore bodies seemed probable. Most of the known ore occurrences in the district were massive sulfide deposits of comparatively high grade.

Geophysical application was favored because the topography of much of the district is even. Owing to the considerable magnetite usually associated with the ore, magnetometer methods would doubtless be applicable. Since massive sulfide ore bodies generally are good conductors, electrical and electromagnetic methods also probably would be suitable.

The initial step in evaluating these various geophysical methods was to determine magnetic susceptibility, electrical conductivity, and density of typical samples from known ore deposits and from various country rocks in the district. Only

6/ Thurmond, Robert E., work cited in footnote 5, p. 64.

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approximate determinations were made to find the order of magnitude in physical-property contrasts. Methods and equipment for making such determinations are described in most textbooks on geophysical prospecting.7/

By using these data and employing formulas derived for computing anomalies8/ resulting from simple shapes, the magnitude of anomalies was estimated for varying sizes or bodies at different depths. These calculations indicated that an average ore body for the district might be detected by magnetic methods under as much as 200 feet of cover. Electrical methods also appeared to offer a favorable application, but density contacts were too low for the use of gravity methods.

The magnetic method was selected for the initial field testing of known ore bodies because it is inexpensive, rapid, and likely to give the most clear-cut results. Several known ore occurrences in the district were selected. A standard-temperature vertical-intensity magnetometer was used.9/ Instrument sensitivity was approximately 20 gammas per scale division.

In each area selected for field testing magnetometer profile lines were laid out normal to the strike of known ore zones. Magnetometer readings were taken along these profile lines at intervals of 50 feet, except where high magnetic gradients indicated a need for closer spacing. Standard methods of diurnal corrections were employed, and final data were considered to be accurate to plus or minus 6 gammas.

Two areas showed magnetic anomalies associated with known ore zones. One of these was the Mineral Hills area. Therefore, a detailed magnetometer survey was undertaken in the undeveloped area east of Mineral Hills, where ore deposits probably occurred under alluvial cover. This method of survey was the same as that described for field tests, except that readings were taken on a grid system. The magnetometer crew consisted of two men, an observer and a recorder. Between 60 and 70 stations could be read in 8 hours. Gridlines were laid out with a transit by the crew; 1 day's surveying was usually sufficient for a week's magnetometer work.

In the process of this surveying 1 area of magnetic anomaly was found about 1 mile east of the Mineral Hill mine in the area of alluvial cover. Although this magnetic high (about 400 gammas above normal) compared favorably with the anomalies previously observed over known ore, it was felt that the area should be checked with other geophysical methods before drilling. Because known nearby ore zones had shown high electrical conductivity, it was decided to check the area with electromagnetic methods. Since equipment was not available, it was designed and constructed by the company.

7/ Heiland, C. A., Geophysical Exploration: Prenctice-Hall, Inc., New York, N. Y., 1940, 1013 pp.
Jakosky, J. J., Exploration Geophysics: Time-Mirror Press, Los Angeles, Calif., 1940, 786 pp.
Joyce, J. W., Manual on Geophysical Prospecting With the Magnetometer: Hobart Publishing Co., Washington, D. C., 2d ed., 137 pp.
Eve, A. S., and Keys, D. A., Applied Geophysics: Cambridge Univ. Press., 1938.

8/ These formulas are found in textbooks previously cited.

9/ This instrument is described in considerable detail by J. W. Joyce, work cited in footnote 7.

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Heinrichs and Thurmond[10/] describe these methods as follows:

> The final equipment used in the production survey consisted of two tripod-mounted horizontal pickup coils connected to an "R-C" type bridge and high gain portable nulling amplifier. Ground energy was supplied by a 1500 watt, 400 cycle portable gasoline generator connected to a five thousand foot straight wire, grounded at each end. A variable transformer was used to adjust the electrode voltage in order to obtain maximum ground current. This was necessary because of variable stake resistance and ground impedance. All detecting equipment was tuned to 400 cycles. High quality precision resistors, condenser and coils were used in the bridge. Where necessary, each component was carefully compensated for capacitance and inductance in order to obtain accurate and precise calibration over the bridge range. Provision was made to obtain readings by both visual meter and audio nulling***.
>
> Bridge range was plus or minus forty-five degree phase angle difference and 0.2 and 1.9 field intensity ratio. Except for minor generator frequency variation, average instrumental accuracy was approximately 0.2 percent. Overall accuracy varied considerably according to layout conditions. Usually observed loops were closed within a few tenths of a degree in phase and a few hundredths in ratio.
>
> Field procedure was to lay out the grounded electrode line parallel to the assumed structure and down dip. This provided maximum subsurface coupling. Measurements were made with a fixed spacing between pickup coils (usually 100 feet), along lines normal to the electrode line. To avoid the effect of the high-gradient "normal" field, observations were taken along the middle one-third area of the electrode line only and not closer than five hundred feet. Average maximum distance from the electrode line for reliable readings was about two thousand feet, although good readings were occasionally obtained out to three thousand feet.
>
> From bridge readings, phase differences and ratio values were obtained by means of the calibration chart and plotted in typical profile and countour form for interpretation. When feasible, a correction was applied for removal of the "normal" ratio gradient***.

A sharp electromagnetic anomaly, both in phase and ratio, was found closely corresponding with the magnetic anomaly (figs. 5 and 6). However, it had shifted approximately 100 feet to the north from the anomaly of the magnetic survey, and it was much sharper than the magnetic high.

The electromagnetic crew consisted of 3 men, 1 observer, and 2 men to transport and set up pickup coils (one of these also recorded). Between 30 and 40 stations were observed in 8 hours by this crew. The same grid lines that had been previously used for magnetic work were used for electromagnetic work.

Heinrichs and Thurmond[11/] also stated:

10/ Heinrichs, W. E. and Thurmond, R. E., A Case History of the Geophysical Discovery of the Pima Mine: Soc. Exploration Geophysicists, 1954, 17 pp.

11/ Heinrichs, W. E. and Thurmond, R. E., work cited in footnote 10.

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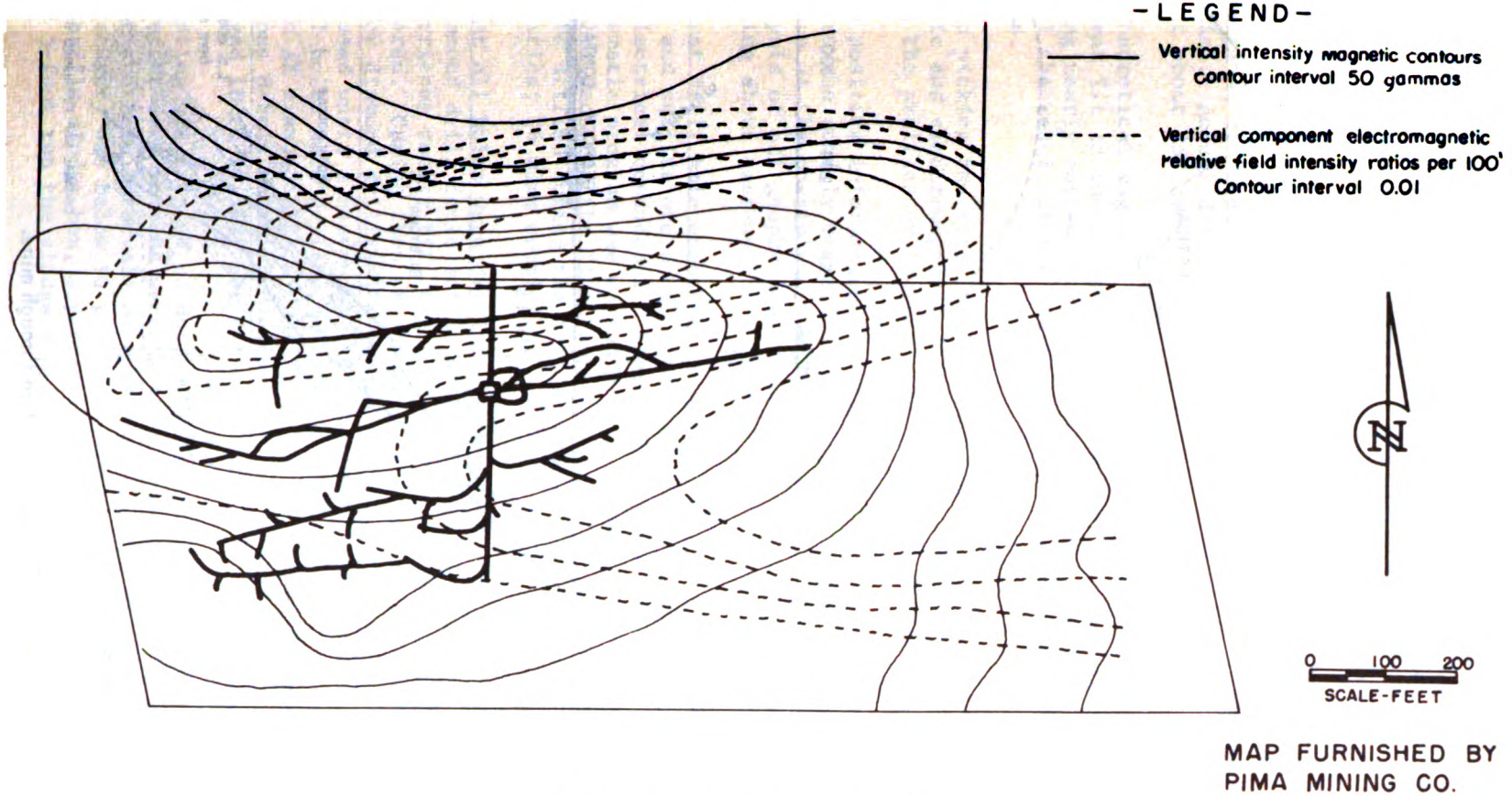

Figure 5. - Geophysical anomalies.

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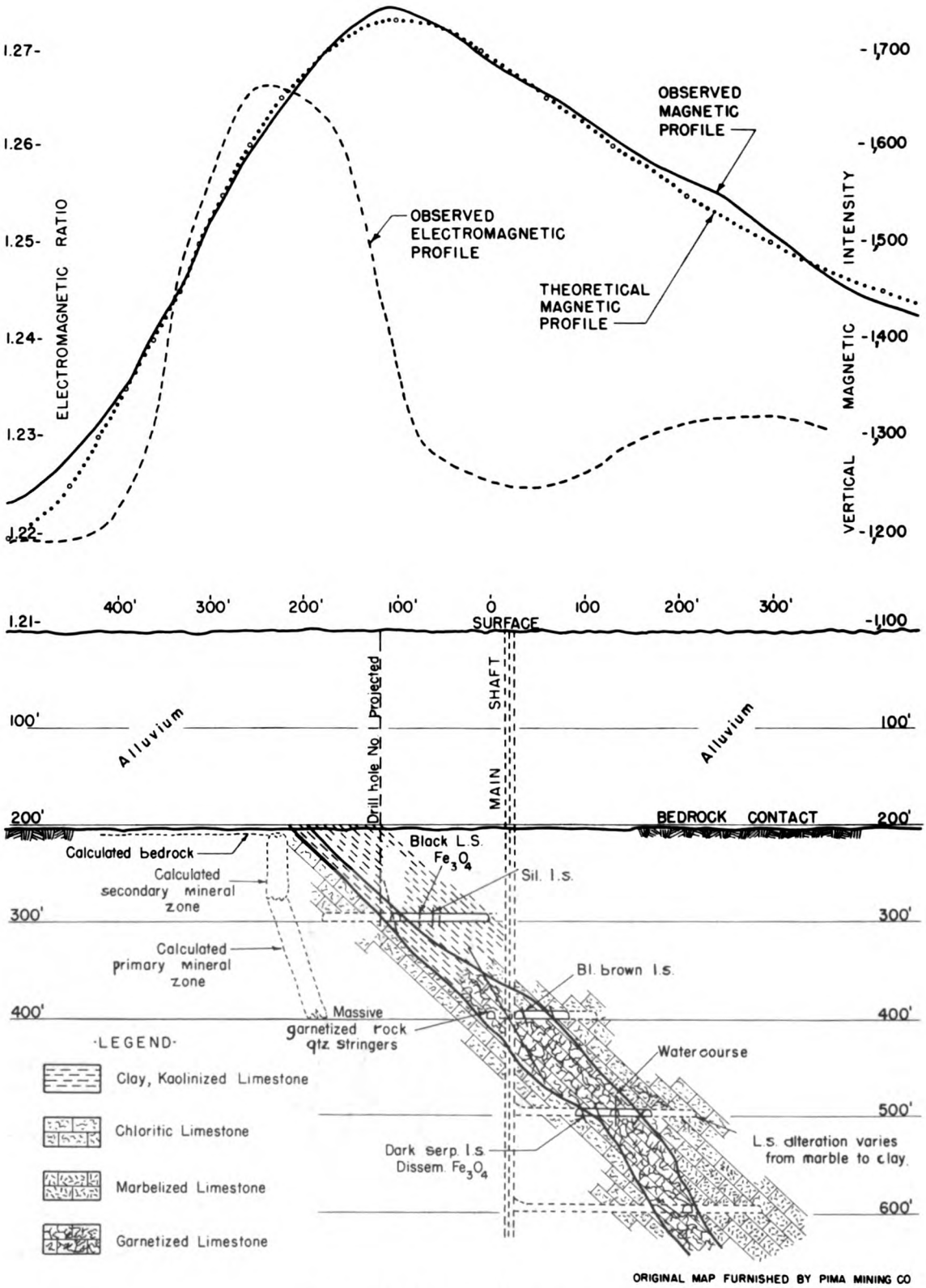

Figure 6. - Section through mine.

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In reducing the geophysical readings to contour maps and profiles, corrections were kept to the minimum necessary only to relate the observed values. Diurnal corrections were made on the magnetic data and all readings related to one main base station occupied each morning and evening. Electromagnetic results were balanced by closing loop traverses and the average 'normal ratio gradient' removed,***.

To assist depth of alluvium estimates, three resistivity depth probes were run. By combining this information with geological extrapolation and study of the magnetic anomaly, the upper surface of the mineralized zone was estimated at 210 feet, plus or minus 25 percent. This allowed for a zone of oxidation. Actual drilling depths ranged from 205 feet to 215 feet with sulfide at about 250 feet.

Theoretical magnetic calculations of assumed conditions which gave an excellent fit to the observed data suggested a rather narrow lenticular zone striking nearly east-west and probably dipping steeply to the south.***. In general the result of the analysis was similar for the other geophysical methods.

In picking the first drill hole locations, reliance was placed on the magnetic and electromagnetic interpretation. This was done by directly comparing the profiles or contour maps of results for each method.

Enough positive information now seemed available to warrant drilling to explore bedrock where the anomaly occurred. The magnetometer survey had indicated that the upper surface of the possible ore body was approximately 210 feet beneath the surface. Analysis of all geophysical data also indicated that the ore body was lenticular, striking about east-west and dipping steeply southward.

The first drill hole encountered bedrock that contained some oxidized material at 209 feet and sulfide ore at 255 feet; the core samples were highly magnetic and were good electrical conductors. Results from this preliminary drilling indicated that a systematic program was warranted. Location of the second hole was guided by information gained from the first hole and from the magnetic contour map. In all, 18 holes were drilled during the initial program; 2 were abandoned because of drilling difficulties; 16 were completed.

At first all holes were drilled with a seismograph shothole drill because a suitable diamond drill could not be obtained. Holes were drilled to bedrock with a 3 7/8-inch tricone rotary bit, using heavy mud to support the walls until bedrock was encountered. Casing then was cemented in the rock. As the shothole drill was not built for diamond drilling, a square kelly was made for AX drill rods. This outfit was used until a heavy-duty, truck-mounted diamond drill could be purchased. However, all holes were drilled to bedrock with a rotary bit then carried in the bedrock with AX diamond bits. Usually in the alluvium, 200 feet of hole could be drilled in one 8-hour shift, and casing set and cemented. Coring in bedrock normally averaged 18 to 20 feet per 8-hour shift.

No sampling was carried on during drilling in the alluvial zone. When bedrock was encountered, core samples were taken at 5-foot intervals. Sludge samples were collected at the same intervals as core samples, but were saved and processed only when core recovery was below 90 percent. The sludge samples were collected in a standard 3-baffle sludge box, approximately 5 feet long and 18 inches wide. At the end of each 5-foot run the sludge sample was allowed to settle, and the water was

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decanted from the top of the sample. The remaining sample was collected and allowed to dry before splitting and preparation for assay.

The total footage of surface core drilling amounted to 7,200 feet before mine development. Drilling costs during the initial exploration phase averaged approximately $5.50 per foot and included sampling, engineering, and assaying.

SAMPLING AND ORE ESTIMATION

In underground development work more reliance was placed on car samples than on channel samples. Car samples were taken from each blasted drift round, from raises, and from stopes.

At a later stage in the development, when lower grade (0.5 percent to 1.5 percent) ore became of interest, several crosscuts were run through low-grade sections, and each round was run through a sampling plant to obtain unusually reliable samples. This plant consisted of a small jaw crusher, a short conveyor to an automatic sampler, and a second conveyor to load into a dumptruck for stockpiling. About 200 pounds of sample was collected from each round (15 tons).

Ore estimates were made in the conventional manner. Areas of ore shoots on each level were measured, then the tonnage in blocks between levels was calculated, using 12 cubic feet per ton. An average assay for the block between levels was calculated.

DEVELOPMENT

After the surface drilling had indicated a copper ore body beneath the alluvial surface, a 400-foot 1 1/2-compartment vertical shaft was sunk from the surface, and levels were opened up at the 300- and 400-foot points to explore and develop the deposit (figs. 6 and 7). The shaft dimensions were 5 by 5 feet for the hoisting compartment and 4 by 5 feet for the manway-counterweight compartment. Eight by 8-inch timber was used in framing-shaft sets, except for the 6- by 8-inch center divider (fig. 8).

Sinking methods were standard, using a mucking pan in the shaft bottom. The pan was filled by hand mucking, then hoisted with an air tugger and dumped into a 20-cubic-foot mine car, caged a few feet above the bottom. During sinking in the alluvial zone no dynamite was used. When hard layers were encountered, pneumatic diggers equipped with clay spades were used to loosen the material before mucking. No major difficulties were encountered in sinking through the alluvium. However, occasionally thick sandy layers resulted in sand runs, which necessitated keeping timber close to the bottom. Sinking progressed approximately 2.3 feet per shift in the alluvium.

Water was found in small quantities just before bedrock was reached. A short distance into bedrock about 160 gallons per minute had been developed. Because adequate pumps were lacking, shaft sinking was slowed somewhat at this point until pumping facilities could be made available. In the early stage of sinking in the rock, electric-power failures also caused several delays. Overall sinking in the rock progressed slightly less than 1 foot per shift. On each of the 3 shifts, the sinking crew consisted of 3 shaft men in the bottom, 1 top lander, and 1 hoistman. In addition, a blacksmith-mechanic, a blacksmith-mechanic's helper, and a timber framer comprised the service crew.

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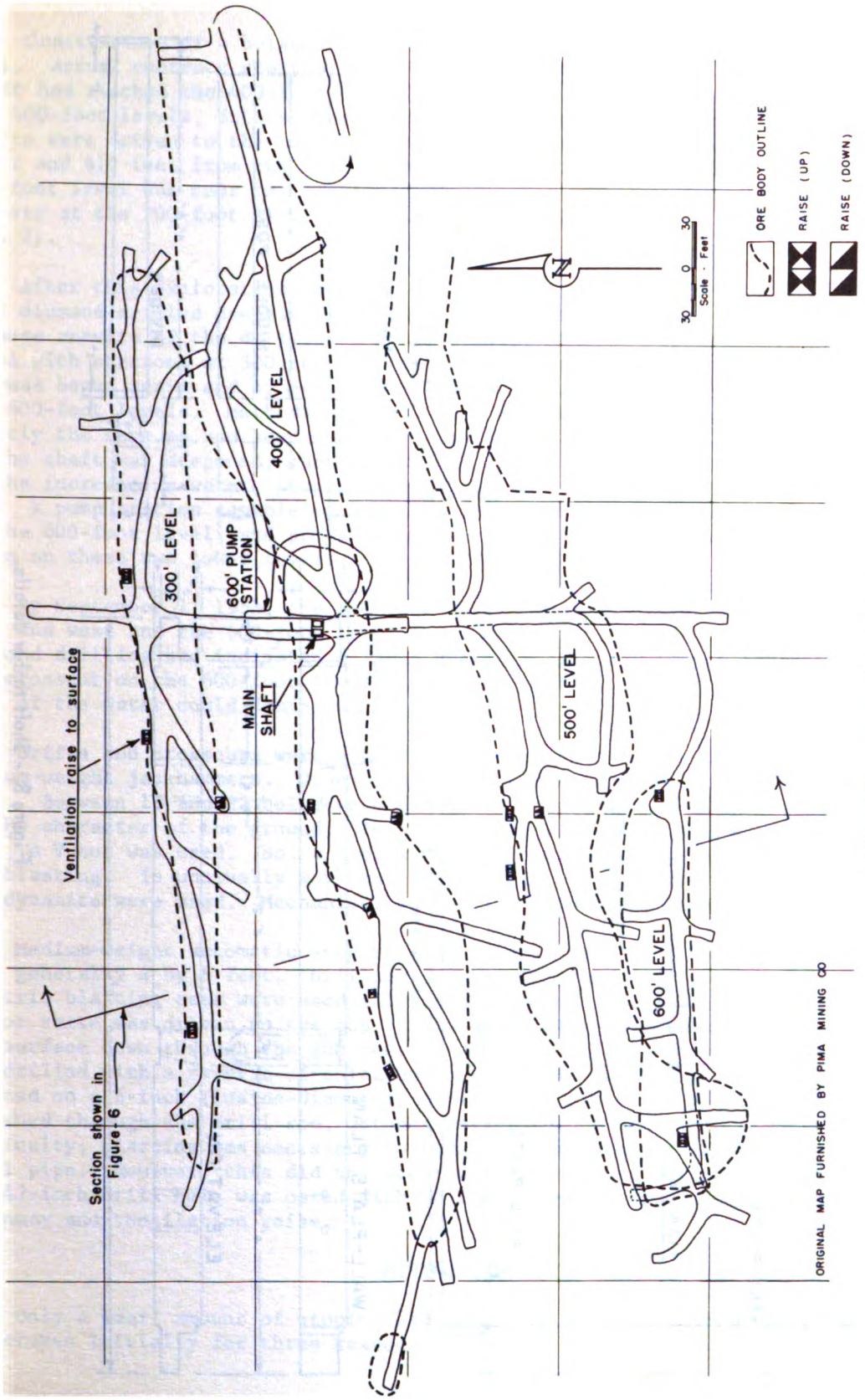

Figure 7. - Composite mine map.

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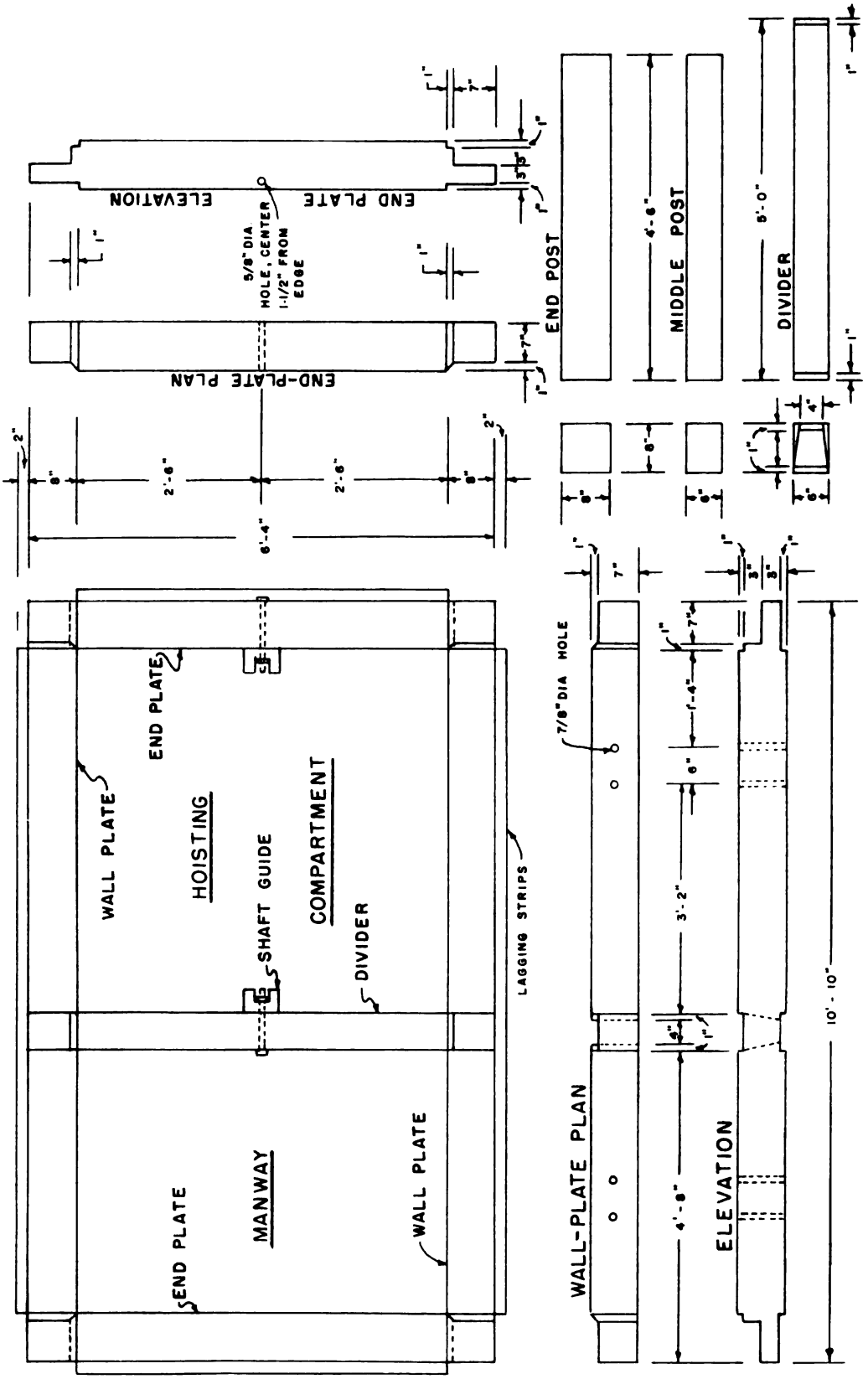

Figure 8. - Shaft timber details.

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Construction of a hoisthouse and other surface buildings was begun in December 1951. Actual contract shaft sinking was begun in January 1952. By May 1952 the shaft had reached the 400-foot level. After shaft stations had been cut on the 300- and 400-foot levels, drifts were started to explore the ore body on both levels. Drifts were driven to the east and west on each level to 925 feet on the 400-foot level and 610 feet from the main crosscut on the 300-foot level. The shaft on the 400-foot level was near the center of the ore body but was some distance from the deposit at the 300-foot level, as the ore body dipped about 45° to the south (see fig. 7).

After this exploration work was done on the 300- and 400-foot levels, 9 holes were diamond-drilled downward from the lower level to explore the deposit at depth. Because results of the drilling were favorable, sinking the shaft to the 600-foot level with stations at 500 and 600 feet was desired. In November 1952 shaft sinking was begun again and by April 1953 had been completed, with stations on the 500- and 600-foot levels. Methods and crew size for this second phase of shaftwork were exactly the same as had been employed previously. Additional water was encountered as the shaft was deepened; the maximum was about 450 gallons per minute. In spite of the increase in water, progress was about the same as for the initial shaft sinking. A pump station capable of handling about 1,000 gallons a minute was excavated on the 600-foot level, and pumps were installed. Lateral development work then was begun on these two lower levels.

By September 1, 1953, the 500-foot level had been explored for 600 feet to the east and west and the 600-foot level for 400 feet to the west (fig. 7). Preliminary diamond drilling had indicated a large quantity of water in the formations east of the crosscut on the 600-foot level. Drifting in this direction was stopped until some of the water could drain out.

Drifts and crosscuts were 5 by 7 feet in cross section and were driven with medium-weight jackhammers. Generally, burn cuts were used for drifts and crosscuts. Between 18 and 22 holes were enough for breaking a 5-foot round, depending on the character of the ground. In a few areas where the ground was difficult to pull, a V-cut was used. No. 6 caps were used, with 40-percent ammonia-base dynamite for blasting. In unusually wet headings electric blasting caps and 40-percent gelatin dynamite were used. Mechanical loaders were used for mucking.

Medium-weight automatic stopers were used in raising. Raise cross sections were generally 4 by 6 feet. Drilling and blasting were similar to those in drifts; electric blasting caps were used only in wet raises. On the 300-foot level a 4- by 6-foot raise was driven to the top of the bedrock. A 42-inch hole was drilled from the surface down through the 200 feet of alluvium to contact this raise. This hole was drilled with a reverse-circulation rotary drill employing an eccentric bit mounted on a 6-inch (inside-diameter) drill rod. Since all drill cuttings were returned through the drill rod, stones larger than 6 inches in diameter presented difficulty; blasting was necessary to reduce their size for passage through the drill pipe. However, this did not occur often enough to be a major difficulty. The 42-inch drill hole was cased with 36-inch-diameter iron casing, then used for a manway and ventilation raise.

MINING (STOPING)

Only a small amount of stoping had been done before January 1955. Stoping was undertaken initially for three reasons:

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1. To gain additional information about the ore body.

2. To experimentally determine an applicable stoping method if the ore body was to be mined with underground methods.

3. To supply enough ore for direct shipment to pay development and exploration costs.

Initially it was decided that a ground-support method would have to be used because of the relatively flat dip of the ore body and the rather incompetent hanging wall. For this preliminary stoping square-set slots, 2 and 3 sets wide normal to the strike, were laid out, leaving 10-foot pillars between adjacent slots. It was planned to fill these slots with gob upon completion and to Mitchell slice the alternate pillars. Several slots were completed and filled, but none of the pillars were extracted because the mine was changed to an open pit before this became necessary.

Medium-weight stopers were used for drilling, and the ore generally was broken by means of breastholes. Blasting was done with No. 6 blasting caps and fuse and 40-percent ammonia-base dynamite. Muck was slushed to the chutes with double-drum air hoists.

Until June 1955, 69,000 tons of ore averaging 6-percent copper had been shipped; a little over half was produced from stoping.

TRANSPORTATION

Hoisting in the shaft was done with a 112-hp. double-drum, electric hoist with a single, counterweighted cage at a speed of about 700 feet per minute.

Ore and waste were trammed on the levels in 20-cubic foot cars pulled by small 1-1/2-ton storage-battery locomotives. Cars were caged to the surface, and muck was dumped into the ore or waste bin by a rotary dump on top of the bin. As many as 125 cars of muck was hoisted and dumped in one 8-hour shift; the rotary dump speeded this work to a large degree.

VENTILATION

Forced ventilation was provided in the Pima mine by a 10,000-cubic-feet a minute exhaust fan, which was situated at the top of the 36-inch round raise. Air traveled down the main shaft, out through the levels, then back to the 300-foot level and on to the surface exhaust fan through the round raise.

Auxiliary ventilation on the levels was provided by small blowers, with vent tubing where needed.

MINE DRAINAGE

After the shaft had been deepened to the 600-foot level, a permanent pump station was excavated on that level with pumps capable of pumping 1,000 gallons per minute directly to the surface. From 250 to 275 gallons of water per minute was pumped during underground operations.

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SAFETY MEASURES

All bosses and about half of the men at the Pima mine were trained in first aid. A first-aid station with stretcher was available at the shaft collar and at each shaft station.

A monthly safety meeting was held, usually on the 400-foot-level station, where motion pictures were shown and lectures on safety were given, either by company officials, by the deputy State mine inspector, or by an engineer from the Health and Safety Division of the Federal Bureau of Mines.

COSTS

Data on dollar costs at the Pima mine are not available. Prevailing wages in the district were paid to all employees. A bonus system also was used in the mine, under which the men were paid a certain amount per square set, etc.; this bonus was additional to standard wages. Miners' bonus usually averaged about 50 percent of base pay.

Production in stopes during underground work averaged 12 tons per man-shift; total underground averaged 11 tons per man-shift.

In drifting and crosscutting the average advance was 3.0 feet per man-shift for men working at the face.

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